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(54) **COMPUTER INPUT DEVICE WITH
INERTIAL INSTRUMENTS**

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G06F 3/03 (2006.01)
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CPC **G06F 3/03** (2013.01); **G06F 3/03543**
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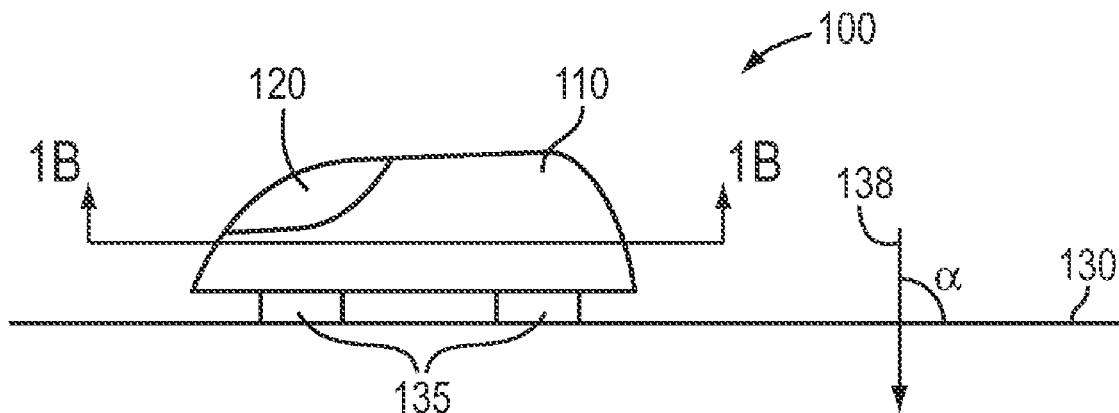
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(57) **ABSTRACT**

A computer input device includes, in one embodiment, at least two accelerometers, at least two gyroscopes, and a processor within a housing. Signals from the accelerometers and the gyroscopes are utilized to determine the relative motion of the computer input device.

26 Claims, 2 Drawing Sheets



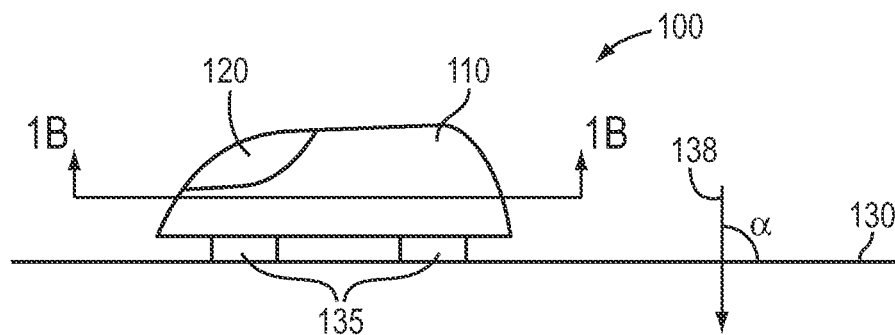


FIG. 1A

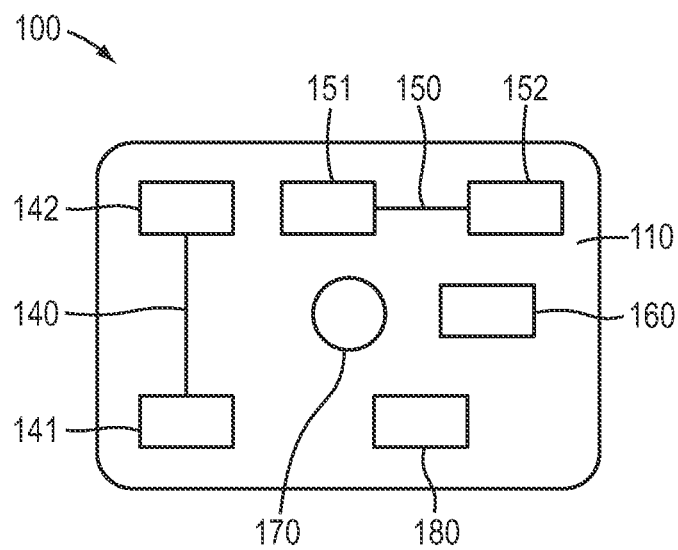


FIG. 1B

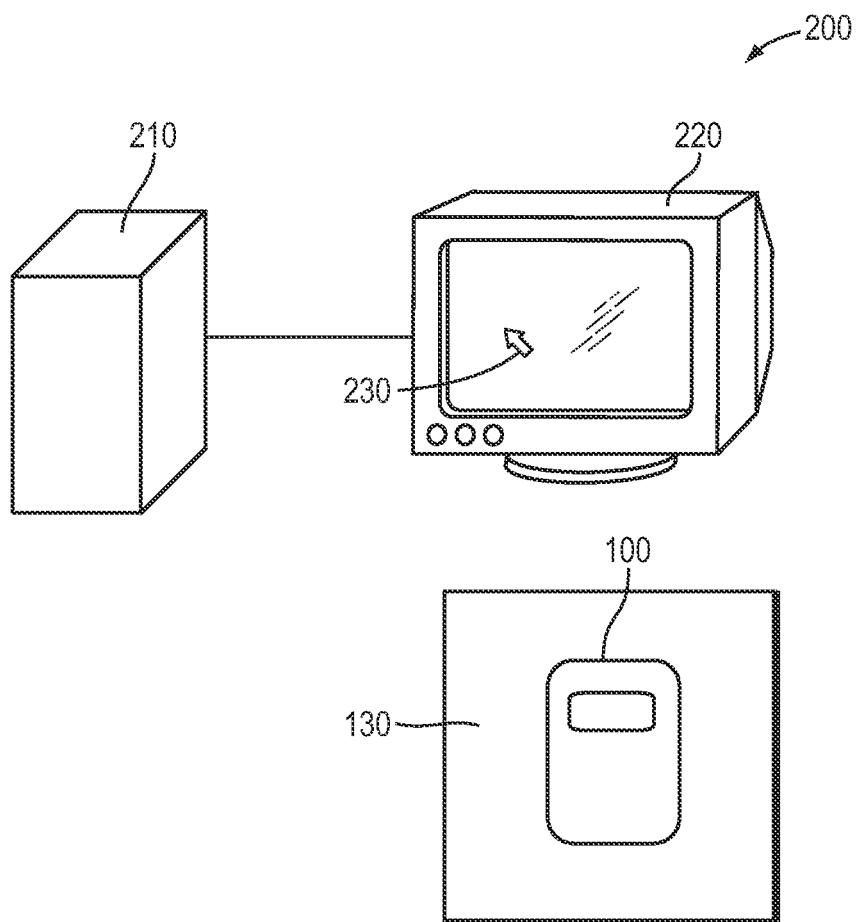


FIG. 2

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COMPUTER INPUT DEVICE WITH INERTIAL INSTRUMENTS

FIELD OF THE INVENTION

This invention relates generally to computer input devices, and in particular to computer input devices incorporating inertial instruments.

BACKGROUND

The importance of highly functional input devices for computing devices such as computers has grown in concert with the rise in functionality and speed of the computing devices themselves. One popular computer input device is the mouse. User-directed motion of a mouse is translated into motion of a cursor or other pointer on the computer display, and buttons, wheels, etc. on the mouse are utilized to, for example, select various images on the display. Conventional mechanical mice (or mouses) incorporate a roller ball. Sensors within the mouse detect the motion of the ball as the mouse is manipulated. However, the moving parts of mechanical mice frequently become contaminated with dust or other particulates, deleteriously impacting mouse performance.

One way to overcome the shortcomings of mechanical mice is to use optical sensors within the mouse to detect its motion. A mouse incorporating optical sensors, frequently termed an "optical mouse," includes a light source, such as a laser or light-emitting diode, and a photosensor. Light from the light source is transmitted toward and reflects off of a surface as the mouse is moved thereover and the photosensor detects the reflected light many times a second. Movement of the mouse is determined based on slight changes in the images created by the reflected light.

While optical mice have compensated for many of the shortcomings of mechanical mice, they have deficiencies of their own. In particular, the motion of an optical mouse over optically specular, transparent, or highly reflective surfaces is difficult to determine with a high degree of accuracy. Moreover, the light source requires a relatively large amount of power, which may compromise the lifetime of battery-powered wireless mice.

SUMMARY

The foregoing limitations of conventional computer mice are herein addressed by using inertial sensors within a computer mouse to detect movement thereof. The computer mouse incorporating the inertial sensors demonstrates improved performance on surfaces unsuitable for optical mice operation.

In accordance with embodiments of the invention, a computer input device incorporates at least two accelerometers and at least two gyroscopes in a housing. Advantages of this approach include operability of the computer input device on specular or transparent surfaces, as well as improved accuracy, as gyroscope signals correct for any component of gravity detected by the nominally horizontal accelerometers.

In some embodiments, in order to combine the signals from the inertial sensors, a digital filter, for example a Kalman filter, is utilized. Furthermore, an optical sensor package may be incorporated into the computer input device to provide an alternative or complementary positioning system.

In one aspect, embodiments of the invention feature a computer input device having a housing for movement over a substantially two-dimensional surface, a sensor unit including at least two accelerometers and at least two gyroscopes

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within the housing, and a processor for determining relative motion of the computer input device utilizing signals from the accelerometers and the gyroscopes. In an embodiment, the signals from the gyroscopes are utilized to correct for non-uniformity and/or tilt in the substantially two-dimensional surface as the computer input device is moved thereover. An optical sensor for sensing relative motion of the computer input device may also be provided within the computer input device.

The computer input device may include a digital filter, for example a Kalman filter, for combining the signals from the accelerometers and the gyroscopes. Wireless or wired means for transmitting, to a computing device, data indicative of the relative motion of the computer input device may also be included. The housing may include at least one user-operable button, and the computer input device may include means for transmitting, to a computing device, data indicative of the button's operation. The data indicative of the button's operation may be utilized at least in part to indicate that the computer input device is substantially motionless.

In another aspect, embodiments of the invention feature a method of fabricating a computer input device. The method includes providing a housing, and disposing, within the housing: (i) a sensor unit including at least two accelerometers and at least two gyroscopes, and (ii) circuitry, responsive to the sensor unit, for determining movement of the housing over a substantially two-dimensional surface. In an embodiment, an optical sensor for sensing relative motion of the computer input device is provided within the housing. Means for transmitting, to a computing device, the relative motion of the computer input device may also be provided within the housing. In a further embodiment, a digital filter, for example a Kalman filter, for combining the signals from the accelerometers and the gyroscopes may be encoded into the circuitry.

In yet another aspect, embodiments of the invention feature a method of determining relative motion of a computer input device. The method includes providing at least two accelerometers, at least two gyroscopes, and a processor within a housing for movement over a substantially two-dimensional surface. The housing is moved over the substantially two-dimensional surface, and the relative motion of the housing is calculated utilizing signals from the accelerometers and the gyroscopes generated in response to the motion of the housing. The signals from the gyroscopes are utilized to correct for non-uniformity and/or tilt in the substantially two-dimensional surface.

Calculating the relative motion may include combining the signals generated by the accelerometers and the gyroscopes using, for example, a Kalman filter. The relative motion of the housing may also be transmitted to a computing device. The substantially two-dimensional surface may be non-uniform and/or tilted.

In another aspect, embodiments of the invention feature a computer input device including a housing for movement over a substantially two-dimensional surface. Within the housing are (i) means for sensing motion of the computer input device, (ii) means for correcting for non-uniformity and/or tilt of the substantially two-dimensional surface, and (iii) means for calculating relative motion of the computer input device utilizing signals from the means for sensing motion and the means for correcting.

In yet another aspect, embodiments of the invention feature a computing device including a processor, a display electrically connected and responsive to the processor, and a computer input device in communication with the processor. The computer input device includes a housing for movement over a substantially two-dimensional surface, a sensor unit, dis-

posed within the housing, that includes at least two accelerometers and at least two gyroscopes, and circuitry for determining relative motion of the computer input device utilizing signals from the accelerometers and the gyroscopes.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the present invention are described with reference to the following drawings, in which:

FIG. 1A is a schematic side view of a computer input device in accordance with one embodiment of the invention;

FIG. 1B is a schematic cross-sectional view of the interior of the computer input device depicted in FIG. 1A, taken along the line 1B-1B; and

FIG. 2 is a schematic view of a computing device incorporating a computer input device in accordance with one embodiment of the invention.

DETAILED DESCRIPTION

Referring to FIG. 1A, a computer input device **100** includes a housing **110** and at least one user-operable button **120** thereon. The housing **100** may include, or consist essentially of, a rigid material, such as a plastic, and may be sized and shaped for movement (via human user manipulation) over a substantially two-dimensional surface **130**. More specifically, when the computer input device **100** is moved over the surface **130**, at least a portion of a bottom side of the housing **110** remains in contact with the surface **130**. This portion may take the form of a plurality of pads **135**, which facilitate the movement of and/or reduce friction between the housing **100** and the surface **130**. The pads **135** may be integral portions of the housing **110** or may be formed of a different material. In an embodiment, two or more user-operable buttons **120** are included on the housing **100**.

The surface **130** is substantially two-dimensional and is generally rigid. The surface **130** may be substantially optically featureless, specular, and/or transparent. In some circumstances, the surface **130** is tilted, i.e., lies at an angle α less than 90° with respect to the direction of gravity (depicted as direction **138** in FIG. 1A). The surface **130** may have microscopic non-uniformities, texture, and/or undulations such that, while the surface **130** is globally substantially two-dimensional, a computer input device **100** moving across it will experience tilt and motion in a direction normal thereto (the amount of which is small compared to the corresponding amount of motion in the plane of surface **130**).

FIG. 1B represents a schematic cross-section of the computer input device **100** along line 1B-1B of FIG. 1A. As shown, the housing **110** contains sensors and circuitry that cooperate to translate the movement of the computer input device **100** into the motion of a cursor or other pointer on a display of a computing device (further described below). More specifically, as the motion of the computer input device **100** is substantially two-dimensional, the housing **110** contains an accelerometer-gyroscope pair **140**, **150** for each of the two dimensions (termed an X axis and Y axis herein) defining the surface **130**. Accelerometer-gyroscope pair **140**, which tracks motion along the X axis, includes an accelerometer **141** and a gyroscope **142**, while accelerometer-gyroscope pair **150**, which tracks motion in the Y axis, includes an accelerometer **151** and a gyroscope **152**. Circuitry **160** con-

nects electrically to the accelerometer-gyroscope pairs **140**, **150** and processes the electrical signals generated thereby. The circuitry **160** may include, or consist essentially of, a processor, such as a microprocessor or a digital signal processor.

As the computer input device **100** is moved across the surface **130**, the accelerometer-gyroscope pairs **140**, **150** generate signals responsive to the motion. Considering, for example, motion only along the X axis, the accelerometer **141** detects, and generates a signal representative of, the acceleration of the computer input device **100** along the X axis. The new position of the computer input device **100** along the X axis may then be calculated by double integration of the acceleration signal from the accelerometer **141**. The gyroscope **142** detects when the X axis (along which accelerometer **141** detects acceleration) rotates at a slight angle from horizontal due to tilt and/or non-uniformity in the surface **130**. Such rotation causes the accelerometer **141** to detect acceleration due to gravity, and introduces error into the accelerometer **141** signal. That is, the signal from the accelerometer **141** represents not only motion across the plane of the substantially two-dimensional surface **130**, but also acceleration due to gravity at a non-normal angle to the surface **130**. The signal from the gyroscope **142** is utilized to correct the accelerometer **141** signal, i.e., remove therefrom any influence of gravity.

More specifically, the gyroscope **142** detects when the X axis rotates slightly due to tilt and/or non-uniformity, and outputs a signal signifying such rotation. The circuitry **160** utilizes the signal from the gyroscope **142** to correct the signal received from the accelerometer **141** (i.e., the circuitry **160** combines the signals from the gyroscope **142** and the accelerometer **141** by using, for example, a filter or algorithm), thus eliminating error due to the tilt and/or non-uniformity. In an embodiment, the circuitry **160** includes a filter which combines the signals from the accelerometer **141** and the gyroscope **142**. The filter may include, or consist essentially of, a digital filter, such as a Kalman filter, or an analog filter. In an embodiment, the filter may include both analog and digital portions. The filter may also filter noise from the signals from the accelerometer **141** and the gyroscope **142**. The filter or algorithm may be embodied in software (e.g., written in any one of a number of high-level languages, such as FORTRAN, PASCAL, C, C++, C#, Java, Tcl, or BASIC; or in a script, macro, or functionality embedded in commercially available software, such as EXCEL or VISUAL BASIC; or in an assembly language directed to a microprocessor resident on a computer), or hardware (e.g., as an application-specific integrated circuit), or as firmware embedded in a microprocessor. The functionality of the circuitry **160** is straightforwardly implemented by one of skill in the art without undue experimentation.

The accelerometer-gyroscope pair **150** operates in a similar manner, but detects motion along the Y axis, which is substantially perpendicular to the X axis. The accelerometer-gyroscope pairs **140**, **150** operate in tandem with respect to the X-axis and Y-axis components of a particular motion. The circuitry **160** receives the signals from the accelerometer-gyroscope pairs **140**, **150** and determines the motion (and therefore the new position) of the computer input device **100**.

Signals may be output from the accelerometer-gyroscope pairs **140**, **150** even when the computer input device **100** is substantially motionless. For example, signals may be output from the accelerometer-gyroscope pairs **140**, **150** due to sensor drift. In order to prevent spurious results, the filter or algorithm encoded in the circuitry **160** may be tuned or coded so as to indicate a lack of movement when both the velocity

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(obtained by integrating the acceleration signal) and acceleration of the computer input device **100** are very small. Both velocity and acceleration should be considered. For example, if the computer input device **100** is moving at a constant velocity, the acceleration thereof will be very small; therefore, acceleration alone is an insufficient indicator. In one embodiment, the computer input device **100** is considered to be motionless when the detected velocity thereof is less than approximately 0.02 m/s and the detected acceleration thereof is less than approximately 0.1 m/s². These threshold values are approximate and can be tuned for individual sensors and operators.

In some embodiments, the button **120** is operated by a user of the computer input device **100** when the computer input device **100** is substantially motionless. Thus, the filter or algorithm may be coded to consider the computer input device **100** to be motionless when the button **120** is operated, and to be reset based on the current values of the signals from the accelerometer-gyroscope pairs **140**, **150** when the button **120** is operated. In this way, the input device is normalized or calibrated to its environment.

In some embodiments, when the computer input device **100** is substantially motionless, i.e., its sensed acceleration and velocity fall below the thresholds discussed above and/or the button **120** is operated, the signals from the accelerometer-gyroscope pairs **140**, **150** are read and utilized to update the filter or algorithm that converts the signals into motion. The filter or algorithm includes sensor biases which are updated at this time based on the signals from the accelerometer-gyroscope pairs **140**, **150**. A component of any tilt and/or non-uniformity in the surface **130** at the position of the computer input device **100** is included in the new bias for the accelerometers **141**, **151**, thus correcting for the tilt and/or non-uniformity while the computer input device is motionless. Once the computer input device **100** is moved again, the gyroscopes **142**, **152** correct for any additional tilt and/or non-uniformity in the surface **130** as described above.

In an embodiment, the housing **110** also contains an optical sensor **170** that also detects the relative motion of the computer input device **100**. Optical sensor **170** may include a light source, for example a laser or a light-emitting diode, and a detector. Light from the light source is emitted towards the surface **130** and is reflected back to the detector. The detector may compare images from the detected light (at, for example, many times per second) to determine the direction and speed of motion of the computer input device **100**. In an embodiment, the optical sensor **170** is utilized in parallel with the accelerometer-gyroscope pairs **140**, **150**. In another embodiment, a user may select one of the optical sensor **170** and the accelerometer-gyroscope pairs **140**, **150** to be operative at a given time—the other may then be powered down to decrease power consumption.

Referring to FIG. 2, the computer input device **100** may be utilized as a component of a computing device **200**. The computing device **200** includes a processor **210** electrically connected to a display **220**. The processor **210** and the display **220** may be housed as separate units connected wirelessly or by wire, or may be housed together in the same package. The processor **210** may include, or consist essentially of, a micro-processor or other integrated circuit. In an embodiment, the processor **210** is also in electrical connection with other components generally found associated with a personal computer, for example storage media and/or input devices, such as a keyboard (not shown). The computer input device **100** may be in electrical communication with the processor **210**. In an embodiment, a conductive cable (not shown) connects the computer input device **100** to the processor **210**. In another

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embodiment, the computer input device **100** includes a transmitter module **180** (see FIG. 1B) that wirelessly transmits, for example by radio-frequency or infrared signal, signals associated with the motion of the computer input device **100** to the processor **210**. The signals may be received by the processor **210** and translated into corresponding motion of a cursor **230** on the display **220**.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects as illustrative of, rather than limiting on, the invention described herein.

What is claimed is:

1. A computer input device, comprising:

a housing for movement over a substantially two-dimensional surface;

a sensor unit, disposed within the housing, comprising a plurality of inertial sensors, at least two of the inertial sensors being accelerometers and at least two of the inertial sensors being gyroscopes; and

a processor for determining relative motion of the computer input device utilizing signals from the accelerometers and the gyroscopes, the signals from the gyroscopes indicating rotation of the computer input device about an axis perpendicular to the direction of gravity due to non-uniformity or tilt of the substantially two-dimensional surface as the computer input device is moved thereover, and the signals from the accelerometers indicating acceleration of the computer input device;

wherein the processor is configured to utilize the signals from the gyroscopes to correct the signals from the accelerometers for acceleration error introduced by gravity due to the non-uniformity or tilt of the substantially two-dimensional surface as the computer input device is moved thereover.

2. The computer input device of claim 1, further comprising an optical sensor for sensing relative motion of the computer input device.

3. The computer input device of claim 1, further comprising a digital filter for combining the signals from the accelerometers and the gyroscopes.

4. The computer input device of claim 3, wherein the digital filter comprises a Kalman filter.

5. The computer input device of claim 1, further comprising means for transmitting, to a computing device, data indicative of the relative motion of the computer input device.

6. The computer input device of claim 1, further comprising:

at least one user-operable button disposed on the housing; and

means for transmitting, to a computing device, data indicative of the button's operation.

7. The computer input device of claim 6, wherein the data indicative of the button's operation is utilized at least in part to indicate that the computer input device is substantially motionless.

8. A method of fabricating a computer input device, the method comprising:

providing a housing; and

disposing, within the housing, (i) a sensor unit comprising a plurality of inertial sensors, at least two of the inertial sensors being accelerometers and at least two of the inertial sensors being gyroscopes, and (ii) circuitry, responsive to the sensor unit, for determining movement of the housing over a substantially two-dimensional surface by, at least in part, utilizing signals from the accel-

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erometers and gyroscopes, the signals from the accelerometers indicating acceleration of the housing and the signals from the gyroscopes indicating rotation of the housing about an axis perpendicular to the direction of gravity due to non-uniformity or tilt of the substantially two-dimensional surface as the housing is moved there-
over, and correcting, based on the signals from the gyroscopes, the signals from the accelerometers for acceleration error introduced by gravity due to the non-uniformity or tilt of the substantially two-dimensional surface as the housing is moved thereover.

9. The method of claim 8, further comprising providing within the housing an optical sensor for sensing relative motion of the computer input device.

10. The method of claim 8, further comprising providing within the housing means for transmitting, to a computing device, data indicative of the movement of the housing.

11. The method of claim 8, further comprising encoding into the circuitry a digital filter to combine signals from the accelerometers and the gyroscopes.

12. The method of claim 11, wherein the digital filter comprises a Kalman filter.

13. A method of determining relative motion of a computer input device, the method comprising:

moving a housing over a substantially two-dimensional surface, the housing comprising a plurality of inertial sensors and a processor, at least two of the inertial sensors being accelerometers and at least two of the inertial sensors being gyroscopes;

calculating the relative motion of the housing utilizing signals from the accelerometers and the gyroscopes generated in response to the motion of the housing, the signals from the gyroscopes indicating rotation of the housing about an axis perpendicular to the direction of gravity due to movement of the housing over the substantially two-dimensional surface and the signals from the accelerometers indicating acceleration of the housing; and

correcting, based on the signals from the gyroscopes, the signals from the accelerometers for acceleration error introduced by gravity due to non-uniformity or tilt of the substantially two-dimensional surface as the housing is moved thereover.

14. The method of claim 13, wherein the substantially two dimensional surface is non-uniform.

15. The method of claim 13, wherein the substantially two dimensional surface is tilted.

16. The method of claim 13, wherein calculating the relative motion comprises combining the signals generated by the accelerometers and the gyroscopes.

17. The method of claim 16, wherein the combining comprises utilizing a Kalman filter.

18. The method of claim 13, further comprising transmitting the relative motion of the housing to a computing device.

19. A computer input device, comprising:

a housing for movement over a substantially two-dimensional surface;

means, disposed within the housing, for sensing acceleration of the computer input device;

means, disposed within the housing, for sensing angular motion with regard to an axis perpendicular to the direction of gravity due to at least one of non-uniformity or tilt of the substantially two-dimensional surface as the housing is moved thereover;

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means for correcting for an acceleration error introduced by gravity due to the non-uniformity or tilt of the substantially two-dimensional surface as the housing is moved thereover; and

means, disposed within the housing, for calculating relative motion of the computer input device utilizing signals from (i) the means for sensing acceleration, (ii) the means for sensing angular motion, and (iii) the means for correcting.

20. A computing device, comprising:

a processor;

a display electrically connected and responsive to the processor; and

a computer input device in communication with the processor, comprising:

a housing for movement over a substantially two-dimensional surface,

a sensor unit, disposed within the housing, comprising a plurality of inertial sensors, at least two of the inertial sensors being accelerometers and at least two of the inertial sensors being gyroscopes, and

circuitry for determining relative motion of the computer input device utilizing signals from the accelerometers and the gyroscopes, the signals from the gyroscopes indicating rotation of the computer input device about an axis perpendicular to the direction of gravity due to non-uniformity or tilt of the substantially two-dimensional surface as the computer input device is moved thereover and the signals from the accelerometers indicating acceleration of the computer input device,

wherein the circuitry is configured to utilize the signals from the gyroscopes to correct the signals from the accelerometers for an acceleration error introduced by gravity due to the non-uniformity or tilt of the substantially two-dimensional surface as the computer input device is moved thereover.

21. The computer input device of claim 1, further comprising:

circuitry for calibrating at least one of the inertial sensors by updating a bias of the inertial sensor based on a signal value received directly therefrom when the computer input device is determined to be motionless.

22. The computer input device of claim 21, wherein the computer input device is determined to be motionless when either (a) a velocity of the computer input device is below a velocity threshold and an acceleration of the computer input device is below an acceleration threshold or (b) a user-operable button disposed on the computer input device is depressed.

23. The computer input device of claim 21, wherein the updated bias comprises a component of at least one of the non-uniformity or tilt of the substantially two dimensional surface.

24. The method of claim 13, further comprising:

calibrating at least one of the inertial sensors by updating a bias of the inertial sensor based on a signal value received directly therefrom when the housing is determined to be motionless.

25. The method of claim 24, wherein the housing is determined to be motionless when either (a) a velocity of the housing is below a velocity threshold and an acceleration of the housing is below an acceleration threshold or (b) a user-operable button disposed on the housing is depressed.

26. The method of claim **24**, wherein the updated bias comprises a component of at least one of the non-uniformity or tilt of the substantially two-dimensional surface.

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